BRAIDING TRIAXIAL WEAVES: 
ENHANCEMENTS AND DESIGN FOR ARTWORKS

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Triaxial weaves are characterized by three axes (tri-axial) of yarn interacting at 60 degrees. In the eighth edition of their standard work [11, p.116], Wingate and Muhler state further, “There may be two intersecting yarns introduced from the warp direction at an angle to one filling or one warp with two fillings introduced at an angle to it.” Figure 1 shows these two configurations in the simplest of the 25 triaxial weaves, the basic weave.

In a previous paper [9], I have described the variations of the basic weave, shown the use of triaxial weaves in various crafts, and surveyed several looms that manipulate diagonal elements. Though largely concerned with industrial looms and patented triaxial weaves, my aim in that paper was to discover a way for handweavers to have access to the wonderful potential of triaxial weaves as a way of exploring color, texture, and design in fiber arts. In a second paper [8], I have described a method, derived from traditional braiding techniques (thus the term triaxial braiding), of using triaxial weaves to produce artworks on an unmodified handloom. In this paper, after a brief review of that technique, I describe enhancements to it that greatly broaden the capacity of triaxial braiding as a means of artistic expression and end with some observations for designing with three directions of yarn.

Figure 2 shows the setup for triaxial braiding on a loom. In industrial triaxial weaving, the warp ends are the diagonal elements, as in Figure 1B, but in triaxial braiding, the weft ends are the diagonal elements, as in Figure 1A. The weft in Figure 2 has been wound on a warp winder and slipped onto two additional rods as a warp would be slipped onto lease or cross sticks. Using a warp winder to prepare the weft preserves the order of the weft ends and assures their constant length.

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Figure 1. Basic Weave. A. Vertical warp, diagonal weft.
B. Diagonal warp, horizontal weft.
Figure 2. Loom setup with first row of third variation triaxial weave completed.
Figure 3. A. Third variation with alternative selvedges.
B. Appearance of weave, isolated intersections.
The loops of cord, L, lock the weft ends into their properly spaced positions. After winding the weft ends into butterflies and moving them aside, the warp ends are tied to the warp rod as in conventional weaving.

In the third variation triaxial weave\(^1\), the interaction of the diagonal elements duplicates what is known in braiding as *balanced plain interlacing* [10, pp.31-39]. It is the obvious weave to use in triaxial braiding though many of the more tightly constructed weaves work quite well [8]. Figure 2 shows the first row of braiding with the yarn widely spaced for clarity. A 1-2 threading and 1-2 treadling create the necessary alternating sheds. The reed beats each new row down and maintains even spacing. Figure 3 shows several additional rows and the appearance of the weave at its actual spacing. An isolated intersection and an abstract representation of an intersection are also shown. Note that when tightly packed, warp and weft ends group themselves into pairs.

Working in rows from selvedge to selvedge, at each intersection the ends of the diagonal pairs of weft cross over and under each other and over and under alternate warp ends. As the ends are crossed it is necessary to give the diagonal pairs a slight tug to pull the crimp out of the immediately preceding rows and to tighten the new intersection. In each row, the weft engages only every second pair of warp ends. The active and inactive warp pairs alternate row by row giving a staggered structure to the weave. This staggered structure suggests an alternate 1-2-3-4 threading with harnesses 1 and 2 operating one set of warp ends and harnesses 3 and 4 operating the other set, thus raising only every fourth end at each shed. This makes the braiding easier at close spacings. At the selvedges, the end pair of weft ends reverses direction. But as shown in Figure 3A, when the weft ends reverse, the relative position of the ends also reverses. In works using different colors or textures in each of the weft ends, the alternate selvedge configuration shown preserves the initial relationship of the ends, though the selvedge is somewhat lumpy and uneven when formed this

\(^1\)Variation numbers have been assigned in the order that the weaves are presented in several patents [2,3,6].
Figure 4. A. Setup for large scale works. B. Setup on a frame.
way. Take-up in the weft ranges from 15 to 25 percent, depending on
the material. All of the enhancements and considerations for design
described below derive from this basic technique of triaxially braiding
the third variation triaxial weave.

Though the method described above works well for artworks using
natural fibers and roughly spun synthetics, recent unsuccessful
experience with Kevlar and graphite yarns revealed the importance of
friction in maintaining the integrity of the fabric as work progresses.
Without tension on the diagonal elements, yarns as smooth and slick as
some man made fibers do not stay in place and tend to compact down
too much when beaten, resulting in a great deal of distortion in the
weave.

Large Scale Works.

Winding the weft on a warp winder and slipping it onto two rods as
shown in Figure 2 is convenient but limits the size of the completed
work. Beyond a certain length, the weft ends, wound into butterflies,
become too bulky to handle. For large works, there must be a way to
add new ends as the original ones run out. If the initial weft ends are
wound on a warp winder, however, all ends will run out
simultaneously. The substitution of all the weft ends at the same point
in the work would, besides being an onerous task, weaken the fabric
considerably. Figure 4A shows an alternate setup using one rod to
attach the warp and one rod for the weft. Here, the warp is attached
first and both rods secured with loops of cord and a guide string, e.g.
Weft ends of variable length are then looped around the weft rod
individually. The different lengths assure that the weft ends will not
run out simultaneously. When setting up in this way, a yarn tube
holder or creel placed near the loom simplifies the process and puts the
yarn in easy reach when new ends have to be added. (The manner of
adding them is described below under substitution.)

On a frame, Figure 4B, where the weft ends are too short for
preparation on a warp winder, the same approach works nicely. The
Figure 5. A. Interlinking to reverse direction of weft.  
B. Effect of reversal. C. Substitution.
frame uses turnbuckles, \( t \), to control tension. It is an inexpensive way to learn triaxial braiding.

The description of triaxial braiding given above assumes that the work will be braided straight through to the end without varying from the initial setup. Figure 7 shows such a work. The unfolding design and ever-changing relationships of the yarn, as the diagonal elements zigzag and change direction, produce compelling works and offer the artist fascinating challenges, but even so, is a limited approach to triaxial braiding. If new ends have to be added in large works in any case, why not add new colors or textures of yarn? And must the diagonal elements travel all the way to the selvedge before reversing direction? The techniques of reversal and substitution described below free the artist from the predetermined relationships of a work braided straight through and give him or her intersection by intersection control over the forms and colors in the work.

The third variation weave is isometric, so when braiding straight through, there is no front or back to the work. They are identical. When using reversal and substitution, however, one side becomes the back, or working, side. While it is possible to execute the enhancements from the front, or finished, side, it is much more efficient to work from the back. In the descriptions below, therefore, it is assumed that the working side faces the weaver.

Reversal.

Figure 5A shows how to reverse the diagonal elements before they reach the selvedge. Known as linking in braiding [10, pp.38 and 236], the technique is a fast and simple way to change the initial order of the diagonal elements at will. But whereas in traditional braiding, the linked ends show in the finished work, in triaxial braiding, the warp ends hide the reversal nicely. Figure 5B shows the effects of reversal from the front.
Substitution.

An obvious way to change color in any kind of weaving is the use of dyes. Recently, a Japanese weaver, Osamu Mijajima, has used ikat techniques in triaxial weaves executed on a loom of his own design. The results are beautiful and this approach certainly deserves further exploration, but it is also desirable to be able to lengthen weft ends when the original ends run out and to substitute new colors and textures as a work progresses. The need to tug the crimp out of the diagonal elements at each intersection calls for a means of securing the ends in some way. They cannot simply be overlapped with old ends as in conventional weaving. Two ways to substitute ends, then, are to knot new ones to old ones or stitch new ends into the fabric.

Knotting requires no detailed description. When extending the length of an existing weft end without changing color, the new length can be tied to the old one using the weaver's knot [1, p.516]. When the braiding catches up with the knot, the weaver slides the knot behind the warp. The knot is thus visible only from the working side of the fabric. When a design calls for a precise color change at a given intersection, however, a square knot [1, p.516], tied against and hidden from view by the warp end adjacent to the intersection where the change occurs, is a better knot to use. In either case, if the knot slips through the front of the work, it can be pushed through to the back with the blunt end of a tapestry needle after the work is off the loom. When plying together multiple strands of yarn for each end, any number of strands can be changed in the same manner for subtle transitions of color and texture.

Knots are knots, however, and they do create a rather unsightly back side of the work. This isn’t necessarily a problem in artworks since the working side is hidden from view and works can be backed, but when many changes occur in a small area, crowding the knots together, or if changes occur at the selvedge, so that the weft end changes color as it reverses, an alternative method of stitching new ends into the fabric is

\[ \text{[2] Mr. Mijajima's work was brought to my attention by Noemi Speiser, to whom I am greatly indebted also for her thorough treatise on braiding [10].} \]
useful. Figure 5C shows color changes at the right and left selvedges and in the body of the work. Stitching the new and old ends back along the path of the ends being changed, as shown, helps avoid interference with other changes close by and prevents the stitched in ends from showing on the front. They are stitched back through two or three intersections to hold them in place. After a few rows of braiding, the cut ends should be pulled to tighten the intersection at the color change. The ends can then be clipped close to the fabric. At the selvedges, the new ends must emerge in the proper relationship to the warp ends at the selvedge, as shown in Figure 5C. Figure 6A shows the effects of substitution and Figures 8 and 9 show the use of reversal and substitution in artworks.

Combining Triaxial Braiding With Conventional Weaves.

The degree of control that reversal and substitution allow suggests the possibility of combining triaxial and conventional (biaxial) weaves so that either can become a supplementary technique for the other. Figure 6B shows how reversal and stitching in clipped off ends can clear areas of warp for other weaves, in this case a plain weave. Note that the stitched in ends follow a slightly different path from that in Figure 5C. This is to assure that the warp ends are secured and to prevent long lengths of warp from showing. By implication, any weave could be combined with triaxial braiding in a similar manner.

Sculpture.

A characteristic of triaxial weaves is their ability to bend or curve without distorting the weave\(^3\), but what happens to the weaves when woven off the loom in non-planar configurations? In a study to test the limits of the structural integrity of triaxial weaves and to explore possible uses for them in fiber sculpture, a warp was strung between two opposing struts of a tetrahedron. The plane of the warp was thus twisted 90 degrees. The use of a tetrahedron reflects my long standing

\(^3\)This and other structural properties are reviewed in [9].
Figure 6. A. Effect of Substitution.
B. Triaxial weave combined with plain weave.
Figure 9. ELEMENTS OF CHANCE. 93 x 77 cm. 1984. Substitution, warp and weft. Braided and photographed by author.
interest in the geometry invented by R. Buckminster Fuller. Indeed, the triangulated structure of triaxial weaves is closely related to many principles elucidated by Fuller [4,5]. When the weft ends were braided through the twisted warp, the study revealed some interesting effects. The path of the weft yarn curved to conform to the twist of the warp plane. In a similar study, when the fabric, also severely curved, was removed from its frame, it retained its curved shape. The potential application of triaxial weaves in sculpture is an area that deserves attention.

Design.

In the broadest sense, design is subjective and varies depending upon the experience and purpose of each artist. As with all mediums and techniques, however, there are general considerations inherent in triaxial braiding that can be objectified to serve as a basis for the objective exploration of design in triaxially braided works.

In conventional weaves, where two axes of yarn meet at 90 degrees, the square and its variations—stripes, plaid, checks, etc.—are the basis for designing. In triaxial weaves, where three directions of yarn meet at 60 degrees, the triangle and its variations are the basis for designing. Lantz’s codification and description of the patterns that emerge in triangulated systems, summarized in Figure 10, applies especially well to the third variation triaxial weave [7, pp.22-23]. Isometric graph paper, which is a grid of equilateral triangles, is a useful tool for exploring these shapes and for designing in general. The reversal of the diagonal elements in triaxial braiding produces another motif in the zigzag effect shown in Figure 3B. The inset shows that the hexagon is an exact representation of an intersection and can be rendered abstractly as six triangles. Colors can thus be represented for the directions of the yarn, shown by arrows, of each intersection. Figure 11 shows how such an abstracted representation can be used for planning a work.

With the enhancements described above, the forms in Figure 10 can be emphasized or de-emphasized, shifted around or completely obscured,
though structurally and conceptually they are always present as the basic units of design. The trick is to predict, and thus control, what will happen and where it will happen as a work progresses. The triangulated grid shown in Figure 11 reveals the shapes in Figure 10 and gives the artist a repeating, predictable ground from which to develop complex designs. Once this basic grid is mastered, departures from it are at the command of the artist.

Figure 11 also shows how to set up the grid. The top row of blocks beneath the grid represents the warp. Each block represents a warp pair consisting of two warp ends. The bottom row of blocks represents the weft pairs. The initial colors for warp and weft can be indicated in the blocks. With practice, the blocks can be separated from a rendering of the design and used with sketches as a planning tool. Several key points should be noted. First, in the third variation weave in which ends are paired, there must be one more pair of weft ends than there are pairs of warp ends. (In weaves that are not paired, there must be one more weft end.) Second, when setting up a grid such as that in Figure 11, the total number of warp pairs must be one fewer than a multiple of the number of pairs in the repeating sequence. For example, the repeating sequence in Figure 11 has four pairs and the entire design has 23 warp pairs: $4 \times 6 = 24 - 1 = 23$. Third, the end pairs of warp and weft are left inactive in the first row (see also Figure 4A). One should start with the second row illustrated in Figure 11, but it is easier to understand how the grid works with the terminal pairs inactive as shown. Finally, in the blocks representing the weft pairs, the arrows show that alternating pairs of ends go into the fabric in alternating directions. When the arrows pointing to the right are followed to the right selvedge and the path is then followed back to the left selvedge, it becomes clear that the weft is a single set of rotating elements.

Grids can contain as many pairs in a repeating sequence as needed for a given design and, as in complex plaids, can be used to set up subtle, shifting triangular patterns, especially if several strands, which can be changed individually by substitution, are plied together for each end. Even if a design calls for no visible grid, labeling ends as a conceptual, invisible grid helps tremendously in planning and setting up works and
in keeping track of where one is in the design as the fabric disappears around the cloth beam.

Philosophically, it has always been important to me that forms and images emerge from the technique and that the technique predicts the forms and images that emerge—a marriage of structure and form. My exploration of triaxial weaves, development of the triaxial braiding technique and its enhancements, and the subsequent understanding of the limitations and possibilities of triaxial weaves gained through the use of triaxial braiding has led to the conception of the three directions of yarn as three directions of information, each of which can be changed at will (the warp through knotting and dying) and each of which potentially carries a separate form. Figures 12 and 13 are recent works that reflect this direction of thinking. I have just begun and it is my hope that this and the previous two articles [8,9] will inspire other handweavers to take a serious look at the unique potential for artistic expression available, and now accessible, with triaxial weaves.
Figure 13. THE GIANT UNDERWATER PYRAMIDS.
(You Remember Atlantis pt.1). 143 x 167.5 cm. 1985.
Braided and photographed by the author.
References


Pittsburgh, PA